IS 10060 : 2013
(Reaffirmed 2019)

भारतीय मानक

पावर हाऊस हेतू स्थलों के लिए भूतकनीकी जाँच — रीति संहिता

(पहला पुनरीक्षण)

Indian Standard

GEOTECHNICAL INVESTIGATION FOR POWER HOUSE SITES — CODE OF PRACTICE

(First Revision)

ICS 93.020

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

January 2013 **Price Group 3**

Geological Investigations and Subsurface Exploration Sectional Committee, WRD 5

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Geological Investigations and Subsurface Exploration Sectional Committee had been approved by the Water Resources Division Council.

This standard was first published in 1981. This revision is proposed to reflect the experience gained on the subject since then.

With the increasing demand for power in the country, an increasingly large number of power houses are being built. One of the major requirements in planning, design and construction of these power houses is proper and adequate subsurface investigation. The object of subsurface and related site investigation is to provide the engineer with as much information as possible about the ground conditions, for example, the thickness of overburden and other geological features of the area. This Code has been formulated to serve as a guide in such investigations.

The methods of subsurface investigation enable vertical sections of the strata to be drawn based on core drilling and *in-situ* tests, samples tested for determining characteristics, such as, shear strength parameters, bearing capacity of the soil, permeability, water table, and soil and/or rock type classification. This information together with the normal topographical survey provides the engineer with complete details of the site and enables him to prepare economical designs for the power house structures.

In the formulation of this standard, due weightage has been given to co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

It has been assumed in this standard that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been formulated.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GEOTECHNICAL INVESTIGATION FOR POWER HOUSE SITES — CODE OF PRACTICE

(First Revision)

1 SCOPE

1.1 This standard gives guidance on the type, extent and details of subsurface exploration needed in connection with hydroelectric power houses both surface and underground.

1.1.1 This standard provides guidelines for planning the exploratory work, through various stages of the project development. These recommendations may have to be modified for individual projects, depending upon the site conditions and other conditions peculiar to each project, such as height and importance of the power house and the heterogeneity of foundation formations.

1.2 The term subsurface exploration, as used herein, covers all types of exploration connected with determination of the nature and extent of surface and subsurface media at or near the power house site.

1.3 This standard does not, however, cover the types and methods of exploration for materials of construction for power houses, such as, aggregate and material for riprap.

2 REFERENCES

The standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on these standards are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

IS No.	*Title*
1888 : 1982	Method of load test on soils (*second revision*)
1892 : 1979	Code of practice for subsurface investigations for foundations (*first revision*)
1893 : 1984	Criteria for earthquake resistant design of structures (*fourth revision*)
2131 : 1981	Method for standard penetration test for soils (*first revision*)
5249 : 1992	Method of test for determination of dynamic properties of soil (*second revision*)
5529	Code of practice for *in-situ* permeability test:
(Part 1) : 1985	Tests in overburden (*first revision*)
(Part 2) : 2006	Tests in bedrock (*second revision*)
6955 : 2008	Code of practice for subsurface exploration for earth and rockfill dams (*first revision*)
6926 : 1996	Diamonds core drilling for site investigation for river valley projects — Code of practice (*first revision*)
7317 : 1993	Code of practice for uniaxial jacking test for deformation modulus of rock (*first revision*)
13946	Determination of rock stress — Code of practice.
(Part 1) : 1994	Using hydraulic fracturing technique
(Part 4) : 1994	Using flat jack technique

3 GENERAL

3.1 In the design of some components of power house structure foundations, special attention is given to the effect of vibrations and sensitivity to settlements. Hence, the results of subsurface exploration should provide enough data for the study of these features and exploration should be very detailed and thorough. Faults, shear zones, weathered horizon and joints found in the rock mass constituting the foundation shall be demarcated. All changes in rock type and formation contacts shall be studied in detail.

3.2 The type and extent of exploration shall be commensurate with the size and importance of the project and will depend upon the size of the power house and the type of foundation.

3.3 Subsurface explorations in connection with a power house shall cover a specified area around the power house site and shall be carried out to a specified depth. All subsurface explorations are to be planned and executed subsequent to the geological mapping of the power house complex Depending upon the type of power house, investigation should be required for the following areas of the power house complex:

a) Forebay;
b) Penstocks;
c) Locations of turbine and generators;
d) Switch and transformer yards; and
e) Other power house components.

3.3.1 A complete programme of exploration shall be able to give information regarding the following points:

a) Types of different soil and rock masses that exists in the foundation;
b) Location, sequence, thickness and aerial extent of each soil/rock stratum, including a description and classification of the soils and rocks, their mineral and chemical constituents and their structure, stratification in the undisturbed state, significant geological or other structural features, such as, buried channels, seams, joints and fissures;
c) Depth and type of bedrock as well as the location, sequence, thickness, aerial extent, altitude, depth of weathering, soundness, and description of rock within the depth of exploration [*see* IS 13946 (Part 1) and IS 13946 (Part 4)];
d) Characteristics of the ground water, including whether the water table is perched or normal, influent or affluent, direction of flow of ground water, depth of and pressure in artesian zones and chemical quality of ground water; and
e) Engineering properties of the overburden and bedrocks [*see* IS 5529 (Part 1) and IS 5529 (Part 2)].

3.3.2 Exploration shall also be needed for study of the following problems:

a) Determination of stability of slope adjacent to power house excavation;
b) Determination of the stability and erosion characteristics of the tail race channel (to know, if lining is required);
c) Effect of seepage water on subsurface material; and
d) *Landslides*, *rockfalls and avalanches* — The stability of glacial and fluvioglacial material with thin soil cap, creep of soil covered hill slopes, etc, shall be studied. In the case of power houses placed at the foot of a hill or on a steep hillside, the hill slope shall be examined for existing or potential landslides or rockfalls. The location of power houses in high altitude areas shall take into account the possibility of avalanches affecting the stability of the power houses.

3.4 For soils, test in accordance with IS 2131 and IS 6955 may be conducted at the required locations.

3.4.1 Wherever drilling in rock is resorted to, NX or larger size would be preferably used as large diameter cores would be useful for studying joint patterns and fracturing (*see* IS 6926). As loads are heavy, shear tests on rock samples may be necessary.

3.5 For general principles and procedures to be followed for investigation and sampling, reference may be made to IS 1892. For exploration by pits, trenches, boring, drifts and shafts, references may be made to IS 6955.

3.6 The extent of foundation exploration required for power houses of given size varies from site to site, depending on the subsurface conditions. The exploration generally proceeds in stages, the details of each stage growing out of the one before. It normally follows a learn-as-you-go procedure, in which characteristics of the subsurface geological conditions are developed in progressively greater detail as the exploration proceeds.

3.7 The subsurface exploration required for a power house are grouped under the following stages:

a) Reconnaissance or pre-feasibility stage;
b) Preliminary investigation or feasibility stage;
c) Detailed investigation or DPR stage; and
d) Construction stage.

3.7.1 The type of investigations required for the last 3 stages will be the same, only difference being in the details of information gathered, quantitatively. Therefore, after describing the reconnaissance stage investigations, the type of information required for the last 3 stages are described together and then the quantitative detail of information for all the 3 stages. If it is found that the properties of foundation material vary too much, then, in each bay, information shall be gathered at least at 3 points.

3.8 Type of Information Required

3.8.1 *Settlement*

3.8.1.1 For finding out the safety of the power house, in so far as uniform and equal settlement are concerned, the following investigations shall be carried out:

a) A chart showing the strata below final foundation level up to one-and-a-half times the width of the substructure of the power house housing the main generating equipment shall be prepared. Investigations shall be carried out to find out if there are compressible clay or other objectionable layers within this depth. In rock with adequate bearing characteristics the bore holes need to penetrate only about 8 m. For the purpose of investigation, unless otherwise known, it may be assumed that the foundation of hydroelectric plants generally are 9 m to 12 m below the original ground surface.

b) Safe bearing capacity at the foundation level of the power house site shall be found out in (1) dry, (2) normal, and (3) submerged foundation conditions. To determine safe bearing capacity, plate load test indicated in IS 1888 should be considered.

3.8.1.2 In order to predict any settlement, modulus of deformation of the foundation shall be found for dry, normal and submerged conditions of the strata.

3.8.2 *Sliding*

For the stability of the power house, it is important to see that the horizontal forces acting above any plane and tending to slide the structure along that plane are not greater than the resisting forces of friction or the shear strength of the materials of foundations forming the plane.

3.8.3 *Ground Water Conditions*

In order to find the extent of submergence of the foundation medium, high and low spring levels at the site of the power house shall be recorded.

3.8.4 *Dynamic Stability*

For the determination of dynamic stability, dynamic properties of the soil shall be determined in accordance with IS 5249 and also to the requirements of IS 1893.

3.8.5 Any other characteristics required by the field or design engineer for a particular locality shall also be determined.

4 HYDROELECTRIC SURFACE POWER HOUSES

4.1 Reconnaissance or Pre-feasibility Stage

4.1.1 The scope of investigation during this stage is confined to the investigation of the suitability of constructing a surface hydel power house in the area where the required drop is available to create head for generation of electricity. The investigation with the general reconnaissance of the area shall be done on 1 : 25 000 or 1 : 50 000 scale topographic maps having contour interval of 20 m or 40 m, so as to establish broad topographical and geological features of the foundation material.

4.1.2 In case the site is near hilly slopes, stability of the hill slopes shall be investigated. In sites subject to avalanches, the direction of avalanche routes and the magnitude of avalanches shall be studied.

4.1.3 In case of sites at high altitude, investigation shall clearly bear out the suitability of foundation material with particular reference to the following conditions:

a) Permafrost; and

b) Stability of glacial and diluroglacial material with a thin soil cap.

4.1.4 The hydrogeological conditions of the foundation material shall be investigated in detail.

4.2 Preliminary Investigation or Feasibility Stage

4.2.1 *Objectives, Types and Method of Exploration*

During this stage, data for formulation of the project and extent of detailed investigations, as required, are collected. The coverage of exploration shall be adequate for examination of the feasibility, which includes preliminary estimation of the cost and evaluation of the benefits. This stage also includes studies for preliminary choice of the alignment as well as the height of the power house. This stage of exploration includes the following:

a) Geological mapping on 1 : 1 000 to 1 : 5 000 scale at 1 m to 5 m contour interval;

b) Exploration by test pits, trenches, drifts and shafts;

c) Exploration by geophysical methods;

d) Exploration by drilling using coring and non-coring methods or by other boring methods;

e) Determination of the depth of water table and evaluation of field permeability; observation of temperature, pressure and discharge of springs not at the surface or in exploratory borings, trenches, etc;

f) Field penetration and field density test in overburden; and

g) Laboratory tests on representative samples and undisturbed samples for the determination of engineering properties of

the overburden material.

4.2.2 After locating the most suitable site from the results of reconnaissance stage investigation, information specified in **3.8** shall be found out for one point only situated at the middle of possible power house layout.

4.2.3 In case of location in alluvium soil, investigation shall bring out presence, if any, of layers of silt, peat, quick sand or a high content of clay, which might cause foundation problems.

4.3 Detailed Investigation or DPR Stage

4.3.1 These investigations are required for obtaining data required for detailed design of all structures related to the power house. These investigations shall be conducted at the final location of the power house and appurtenant works fixed from preliminary stage investigations.

4.3.2 In this stage of investigation, all data required for detailed design and preparation of construction drawings shall be collected. Close co-ordination is essential between the work of the organizations for exploration, geological work and design.

4.3.3 Investigations at this stage shall comprise the following :

a) Updation of geological maps on 1:1000 scale;

b) In case of high open cuts, shear parameters of overburden or joints in rocks may be determined by *in-situ* testing;

c) Collection of geological data on joints and other discontinuities must be intensive in DPR stage;

d) Use of geophysical methods to define in detail the subsurface conditions, such as the depth to bed rock or depth to water table in specific sections of the power house base. During this stage, use of borehole geophysical methods, such as electrical logging, as and when required, may be found advantageous to define particular characteristics of overburden and bed rock;

e) Intensive exploration by drilling and pitting (trenches and shafts where found necessary) of the foundation to determine spatial distribution and characteristics of different types of foundation materials in relation to specific design features. Two to four or more holes (covering the area) may be drilled to satisfactorily portray the geological condition and delineate weak and vulnerable zones, if any. Holes shall be drilled to a depth of one to two times the maximum width of the structures or 10 m in the fresh rock whichever is less;

f) In view of slope stability problems, it is imperative that the back slope is investigated by exploratory drifts to especially observe the nature of discontinuities and for rock mechanics test;

g) Defining of geohydrological characteristics of the foundations and their environments through pumping in or pumping out tests, as dictated by site conditions;

h) Ascertaining the groutability of foundations, if required, through trial grouting of specified reaches;

j) If the power house foundation consists of alluvium material (high silt sand deposit, reverine terrace, etc) special field test shall be carried out which shall include,

   1) Drilling of holes;
   2) Standard penetation tests;
   3) Cone penetration tests;
   4) Grain size analyses;
   5) Cyclic simple shear tests;
   6) Resonant column tests; and
   7) Geophysical tests.

   NOTE — Based on the results of the above tests, interpretation may be carried out whether the soil is susceptible to liquefaction under the maximum credible earthquake.

k) *In-situ* rock mechanics tests are to be carried out for determining the load bearing capacity, shear strength parameters (c and Φ) and stress measurement of the foundation.

m) Laboratory tests, namely compressive strength (uniaxial and triaxial), tensile strength; and modulus of elasticity, density, specific gravity, void ratios, porosity and permeability are to be carried out in the rock samples.

4.3.4 Information specified in **3.8** may be obtained for at least one point situated at the middle of the unit bay, erection bay and control bay. More bore-holes may be required, depending upon the geological conditions.

4.4 Construction Stage

Construction stage exploration shall aim at making available data generally for the evaluation of specific foundation preparation and treatment. In case, after actual excavation, it is found that the properties of foundation material vary too much, then, in each bay, information shall be gathered at least at 3 points. A complete record of the foundation features shall be

maintained at this stage. This is essential for the solution of post construction problems, if any. Foundation grade geotechnical mapping on 1 : 100 or 1 : 200 scale should be done.

5 HYDROELECTRIC UNDERGROUND POWER HOUSES

5.1 Reconnaissance or Pre-feasibility Stage

5.1.1 The scope of investigations during this stage is confined to the selection of the most suitable sites from the geological considerations, besides satisfying the engineering requirements. The investigation shall proceed with the general reconnaissance of the area on 1 : 50 000 scale topo-maps having contour of 20 m or 40 m to establish broad geomorphologic features. Lithological characters and attitude of the host rock and its major jointing, shear zone and pattern, and the major structural and tectonic features, such as folds, faults and thrusts, shall be recorded and their significance in terms of the seismicity of the area shall be evaluated. After eliminating obviously unsatisfactory sites, reconnaissance stage explorations shall be done to establish the nature and extent of overburden cover and major active or potential slide features along the slope. Preferably, thinly bedded fissile and highly fractured rocks shall be avoided and slope configuration shall be studied with reference to stability and availability of sound rock cover over the cavity. A programme of surface and subsurface investigations shall be chalked out for the selected site to establish the depth of open and slump joints or potential slide mass as well as depth to sound rock over the proposed cavity.

5.1.2 *Surveys*

5.1.2.1 Topographic survey on 1 : 25 000 or 1 : 50 000 scale shall be carried out, extending from the head race tunnel end to the tail race tunnel end and covering the hill slope for 150 m on either side of the proposed sites of the power house structure and penstocks. This shall be used as a base map for detailed geological mapping in the preliminary stage of investigation to demarcate significant geological and structural features of the area. Generally digitized toposheets on 1 : 50 000 or 1 : 25 000 scale are available from Survey of India.

5.2 Preliminary Investigation or Feasibility Stage

5.2.1 In this stage the objective of investigations is to select the most suitable site for a power house based on the interpretations of surface and subsurface exploration data, and comparative evaluation of the various alternatives. Detailed geological mapping on 1 : 5 000 scale shall be carried out prior to the recommended subsurface exploration and at least the following features shall be recorded:

a) Various lithological units present in the area, their altitudes and continuity, susceptibility to weathering, geometry of the structural weak planes such as joints, nature of filling of the planes of discontinuity, slip planes, shear zones, folds and faults;
b) Demarcation of covered area with remarks on the nature of the material, creep and slide features;
c) Ground water conditions;
d) *Existence and nature of springs* — hot or cold; and
e) Pressure of any oil or gas shows.

5.2.2 Depending upon the site conditions some shallow drill holes to decipher the depth to bedrock and overburden thickness at the site may be done.

5.3 Detailed Investigation or DPR Stage

5.3.1 Geological mapping on 1:1 000 scale with contour interval as dictated by site condition.

5.3.2 The objective of the investigation is to provide a fairly clear picture of the existing geological conditions likely to be present at the power house cavity for design of the cavity and outline of the excavation programme and treatment.

5.3.3 Based on the results of detailed surface geological mapping, a programme of subsurface exploration by drifting shall be made which should extend upto the tentative power house location, in order to have a detailed assessment of geological discontinuities and the stress field present at the power house site. The drift shall preferably run along the long axis of the power house having 2 to 3 cross-cuts on either side extending upto the power house cavity walls. The drift may preferably be kept at the haunch level of the roof arch.

The observations gathered during the exploratory drifting should include,

a) lithologic characteristics of the various rock units;
b) their suitability to tunneling;
c) 3-D geological mapping of the exploratory tunnels/drifts;
d) depth to sound rock;
e) nature, spacing and continuity of prominent joints, slip planes, minor and major shear seams zones; and
f) study of stress field.

Based on the results of subsurface explorations and in *in-situ* stress, suitable recommendations regarding

the location and orientation of the power house cavity shall be decided. If these studies indicate the presence of adverse geological discontinuities with reference to the long axis of the power house, the orientation of the cavity shall be suitably modified keeping in view the prevailing stress field. In general, it is undesirable to have prominent geological discontinuities parallel or nearly parallel to the long axis of the power house or along high walls and rock cuts.

The exploratory drifts also facilitate collection of rock samples of various types for determination of elastic or various other properties in the laboratory in addition to conducting various *in-situ* tests for designing support system, lining and rock blotting.

5.3.4 Critical geological observations shall be made in the exploratory drifts made in the cavity area and the drill holes drilled earlier. The observations in the exploratory tunnel should include limit of slump joints or glide cracks and study of stress field. The drilling and drifting shall be done as per **5.3.3**. In addition, 2 to 3 exploratory drill holes down to draft tube level are required to be done from exploratory drifts. Possibility of mechanized drifting by small diameter TBM (tunnel boring machine) may be explored depending on the site conditions and accessibility. Rock mechanics studies regarding geological discontinuities shall be correlated with surface observations and drill hole data. Suitable number of tests shall be performed for the determination of *in-situ* modulus of elasticity, Poisson's ratio, modulus of deformation, shear parameters and determination of stress field in various directions (*see* IS 7317) and also the properties of important shear zone materials and joint fillings.

5.3.5 Investigations shall cover an area around the cavity of 3 to 5 times its larger dimension, depending upon the geological complexities deciphered in the preliminary investigation stage.

5.4 Construction Stage Investigations

5.4.1 Three dimensional (3 D) mapping on 1 : 100 or 1 : 200 scale of the underground power house cavern should be carried out to identify and delineate lithological bands, structural discontinuities like joints, shears, faults, etc, and water seepage zones. The rock mass classification using Q and RMR shall be attempted on the basis of different key-parameters collected during 3-D mapping. Based on the Q and RMR values, suitable support systems — passive (steel ribs) and active (rock bolts) with wire mesh shotcreting are provided.

During this stage focus should be laid on the instrumentation of cavern. The instrumentation for monitoring the underground power house caverns are categorized into two systems, namely,

a) *Strata monitoring system* — To monitor rock mass deformation, stress changes and pore water pressure.

b) *Support monitoring system* — To monitor deformation and load on supports.

The strata monitoring is done by using single point or multi-point borehole extensometers, closure meters (tape extensometers), peizometers, etc. The support monitoring is done by using load cells, pressure cells and pull out tester. Micro-seismic/ nano-seismic monitoring (real time, on line) is very useful, during construction and post-construction stages, for detecting micro-cracking/displacement/ deformation in rock mass around cavern by fixing sensors or geophones at different locations in boreholes.

The information provided by instrumentation and monitoring yields a better understanding of the structure's response mechanism to various stresses to which they are subjected.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 1986 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

This Indian Standard has been developed from Doc No.: WRD 5 (452).

Amendments Issued Since Publication

Amendment No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.org.in

Regional Offices:		*Telephones*
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	2323 7617 2323 3841
Eastern	: 1/14, C.I.T. Scheme VII M, V.I.P. Road, Kankurgachi, KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: SCO 335-336, Sector 34-A, CHANDIGARH 160022	260 3843 260 9285
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East), MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. DEHRADUN. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAJKOT. THIRUVANATHAPURAM. VISAKHAPATNAM.

Published by BIS, New Delhi